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January 07, 2004

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APPLICATION NUMBER: ***60/424,620***
FILING DATE: ***November 07, 2002***
RELATED PCT APPLICATION NUMBER: ***PCT/US03/32743***

By Authority of the
COMMISSIONER OF PATENTS AND TRADEMARKS

M. K. Hawkins

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11-08-02

PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No. EU470413543US

INVENTOR(S)

Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
Philip J.	Koh	Centreville, Virginia
David T.	Nemeth	Washington, D.C.

☐ *Additional inventors are being named on the _______ separately numbered sheets attached hereto*

TITLE OF THE INVENTION (500 characters max)

A Method of Making Compact, High Performance Microwave Filters Using Micromachining

CORRESPONDENCE ADDRESS

Direct all correspondence to:

☐ Customer Number [ ] *Type Customer Number here* → *Place Customer Number Bar Code Label here*

OR

☒ Firm or Individual Name	Sophia Wireless, Inc.				
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Country	Fairfax	Telephone	(703)961-9573	Fax	(703)961-9576

ENCLOSED APPLICATION PARTS (*check all that apply*)

☒ Specification *Number of Pages* 7
☒ Drawing(s) *Number of Sheets* 5
☐ Application Data Sheet. See 37 CFR 1.76
☐ CD(s), Number
☐ Other (specify)

The PTO did not receive the following listed item(s) 5 sheets of drawings

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT

☒ Applicant claims small entity status. See 37 CFR 1.27.
☒ A check or money order is enclosed to cover the filing fees
☐ The Commissioner is hereby authorized to charge filing fees or credit any overpayment to Deposit Account Number:
☐ Payment by credit card. Form PTO-2038 is attached.

FILING FEE AMOUNT ($): 80.00

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government

☐ No
☒ Yes, the name of the U.S. Government agency and the Government contract number are:
Air Force Research Laboratory, Rome, N.Y.; F30602-02-C-0044

Respectfully submitted,

SIGNATURE PJ Koh

Date 11/7/02

TYPED or PRINTED NAME Philip J. Koh

REGISTRATION NO. (*if appropriate*)

Docket Number:

TELEPHONE (703)961-9573

USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

PTO/SB/17 (10-01)
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FEE TRANSMITTAL for FY 2002

Patent fees are subject to annual revision.

TOTAL AMOUNT OF PAYMENT ($) 80.00

Complete if Known	
Application Number	
Filing Date	
First Named Inventor	
Examiner Name	
Group Art Unit	
Attorney Docket No.	

METHOD OF PAYMENT

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☐ Charge Any Additional Fee Required Under 37 CFR 1 16 and 1 17

☒ Applicant claims small entity status See 37 CFR 1 27

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FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
101	740	201	370	Utility filing fee	
106	330	206	165	Design filing fee	
107	510	207	255	Plant filing fee	
108	740	208	370	Reissue filing fee	
114	160	214	80	Provisional filing fee	80.00

SUBTOTAL (1) ($) 80.00

2. EXTRA CLAIM FEES

			Extra Claims		Fee from below		Fee Paid
Total Claims		-20** =		X		=	
Independent Claims		- 3** =		X		=	
Multiple Dependent						=	

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
103	18	203	9	Claims in excess of 20
102	84	202	42	Independent claims in excess of 3
104	280	204	140	Multiple dependent claim, if not paid
109	84	209	42	** Reissue independent claims over original patent
110	18	210	9	** Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) ($)

**or number previously paid, if greater; For Reissues, see above

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
105	130	205	65	Surcharge - late filing fee or oath	
127	50	227	25	Surcharge - late provisional filing fee or cover sheet	
139	130	139	130	Non-English specification	
147	2,520	147	2,520	For filing a request for *ex parte* reexamination	
112	920*	112	920*	Requesting publication of SIR prior to Examiner action	
113	1,840*	113	1,840*	Requesting publication of SIR after Examiner action	
115	110	215	55	Extension for reply within first month	
116	400	216	200	Extension for reply within second month	
117	920	217	460	Extension for reply within third month	
118	1,440	218	720	Extension for reply within fourth month	
128	1,960	228	980	Extension for reply within fifth month	
119	320	219	160	Notice of Appeal	
120	320	220	160	Filing a brief in support of an appeal	
121	280	221	140	Request for oral hearing	
138	1,510	138	1,510	Petition to institute a public use proceeding	
140	110	240	55	Petition to revive - unavoidable	
141	1,280	241	640	Petition to revive - unintentional	
142	1,280	242	640	Utility issue fee (or reissue)	
143	460	243	230	Design issue fee	
144	620	244	310	Plant issue fee	
122	130	122	130	Petitions to the Commissioner	
123	50	123	50	Processing fee under 37 CFR 1.17(q)	
126	180	126	180	Submission of Information Disclosure Stmt	
581	40	581	40	Recording each patent assignment per property (times number of properties)	
146	740	246	370	Filing a submission after final rejection (37 CFR § 1.129(a))	
149	740	249	370	For each additional invention to be examined (37 CFR § 1.129(b))	
179	740	279	370	Request for Continued Examination (RCE)	
169	900	169	900	Request for expedited examination of a design application	

Other fee (specify) ______

*Reduced by Basic Filing Fee Paid

SUBTOTAL (3) ($)

SUBMITTED BY

Complete *(if applicable)*

Name (Print/Type)	Philip J. Koh	*Registration No. (Attorney/Agent)*		*Telephone*	(703)961-9573
Signature	Ph K			*Date*	11/7/02

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[redacted]

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Chantilly, VA 20151

A Method of Making Compact, High Performance Microwave Filters Using Micromachining

Prior art of micromachined filters includes suspended metal resonators of various kinds. For example, a resonator patterned on a thin dielectric film, such as silicon nitride, which is then suspended in air, is a prior art embodiment of micromachined filters. These prior art patterns show insertion loss that is poorer than that of the filters described here. The reason being that in these prior art filters the resonators are thin metal lines, on the order of electroplated metal, which is typically a few microns. This necessarily concentrates the current, even in the absence of surrounding dielectric, which increases the ohmic losses of the filter. This reduces the Q of a given resonator, and the insertion loss for the filter as a whole. In addition, the thin suspended resonators are susceptible to microphonics, in which mechanical vibration of the filter changes the passband characteristics, modulating the filtered signal.

The filters described in this patent have the advantages of lower insertion loss, immunity to microphonics, and reduced manufacturing complexity. Forming a precise three-dimensional cavity, which is entirely coated in metal, with the exception of the input and output coupling structure, produces the filters. In some instances of this invention, the cavities are formed by taking several silicon wafers and etching them using either anisotropic silicon etch (such as Potassium Hydroxide in water), or reactive ion etching. The wafers then have a seed layer of metal deposited by any number of methods familiar to one skilled in the art. A good conductor, such as gold, is electroplated on top of the seed layer to give a suitable thickness such that the resistivity of the gold is greatly reduced. The conductor should be thick enough so that the energy lost due to ohmic losses in the gold is much less than the energy loss due to energy leaking through the gold and being dissipated in the support silicon. Because of the high Q of the cavities, this number can be significant.

We now describe an embodiment of this invention in the form of a bandpass filter. Bandpass RF filters are constructed out of a series of coupled resonators. By tuning the coupling between the resonators and the frequencies of the resonators, the desired filter characteristics can be achieved. What is needed in the fabrication process is the flexibility to make resonators of the desired frequencies, and to be able to make different couplings between the resonators. A method is also needed for coupling the signal into and out of the series of coupled resonators.

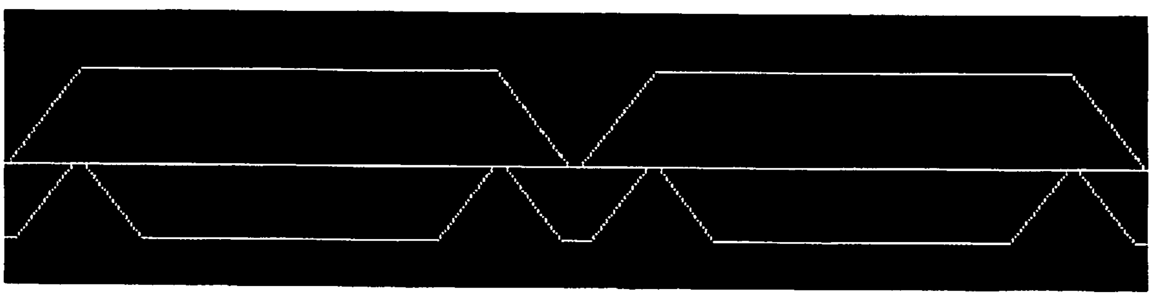
In one embodiment of the invention, the resonators are cavities formed from rectangular pits etched in the silicon. This embodiment starts as three separate <100> oriented silicon wafers. All of the wafers are coated with an etch mask, such as silicon nitride or silicon oxide. These masking layers are patterned using standard

[redacted]

photolithographic techniques. The wafers are then etched in an anisotropic silicon etch; which etches the <111> planes of silicon much more slowly then the other planes. As a result, the precision of the two-dimensional masking layer is transferred to the final three-dimensional pit, as someone skilled in the art can easily see.

The top wafer in the stack is etched until the cavity height reaches a specified depth. Alternatively, an etch stop layer, such as a buried silicon oxide layer, can be used, which makes the etch self-terminating. The masking layer is then stripped. A barrier layer may be grown at this point, such as silicon oxide or silicon nitride. Next, a thin layer of metal is deposited using a standard metal deposition technique, such as sputtering. Finally, metal is electroplated to a thickness sufficient to reduce the ohmic losses as much as possible.

The middle wafer is patterned on both sides, and etched. The etch does not have to be precisely timed, as all the patterns are self-terminating. The bottom wafer does not need to be etched at all, but is covered in metal. The three wafers are bonded together. The bonding can be accomplished any of several methods, as longs as the bond gives good electrical conductivity between the metal on the various wafers. Some examples of suitable bonding methods are direct gold-to-gold thermo compression bonding, or bonding with an intermediate bonding layer, such as Gold-Tin eutectic. Inside the bonded wafers is a series of connected cavities. Shown below is a cross section of the cavities.



The large cavities form the resonators, and the small cavities connecting the resonators form a weak coupling between the resonators. The frequency of each resonator can be adjusted by changing the lateral dimensions of the resonator. The coupling strength can be adjusted by adjusting the lateral dimensions of the coupling cavity. Hence, this process has all of the degrees of freedom required to design a filter. The method of determining the necessary sizes of the different cavities is discussed elsewhere in this document.

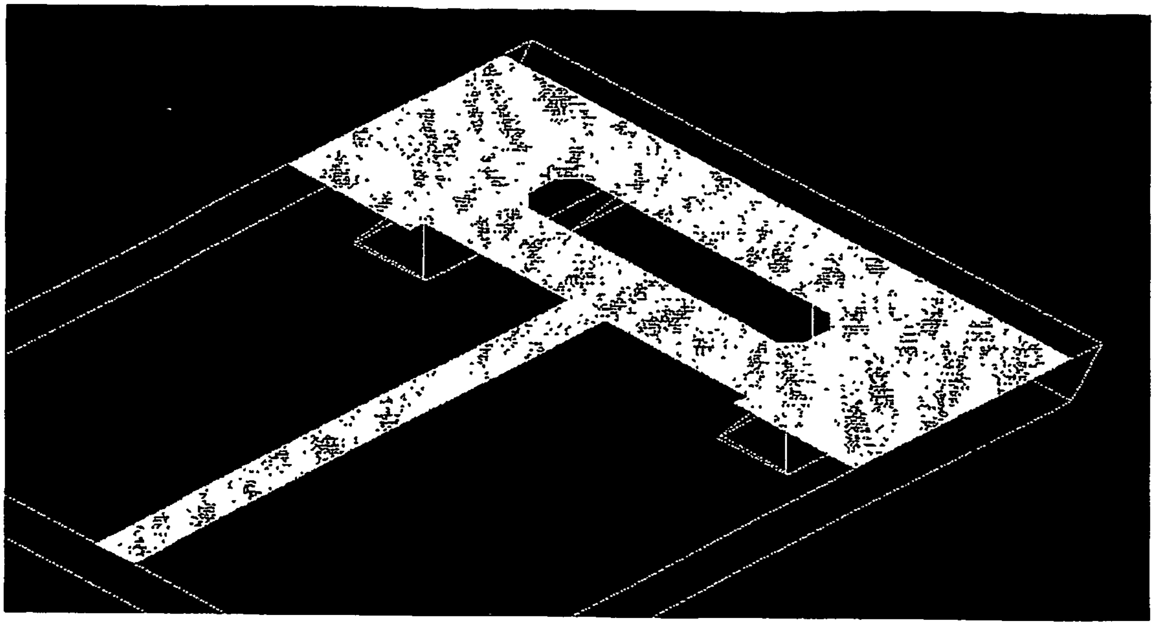
Next, a method of coupling a signal into one end of the filter and out of the other is needed. One embodiment of this will now be discussed. This embodiment of the coupling structure couples a microstrip line formed on wafer one into one of the cavities. The microstrip can be formed by a variety of methods, such as electroplating gold through a patterned photoresist mask, which is a well-known art. This microstrip line ends on a large piece of patterned metal on wafer 1. Because this is a microstrip line, the

fields are carried inside wafer 1 between the patterned line on top and the metal on the bottom, which acts as a ground plane. The signal will continue to travel some distance into the wafer. It passes underneath the point where wafer 2 is bonded to wafer 1. Inside the cavity, there is an opening in the gold on wafer 1 formed at the same time the microstrip line was patterned. There are via holes around this opening, except on the side where the signal comes in. These via holes direct the incoming signal to the opening in the metal, which couples into the first resonant cavity. Because the signal travels through the silicon of wafer 1, this wafer must be made out of very pure silicon to reduce the losses caused by dopants. Such silicon, referred to as high resistivity silicon, is readily available commercially.

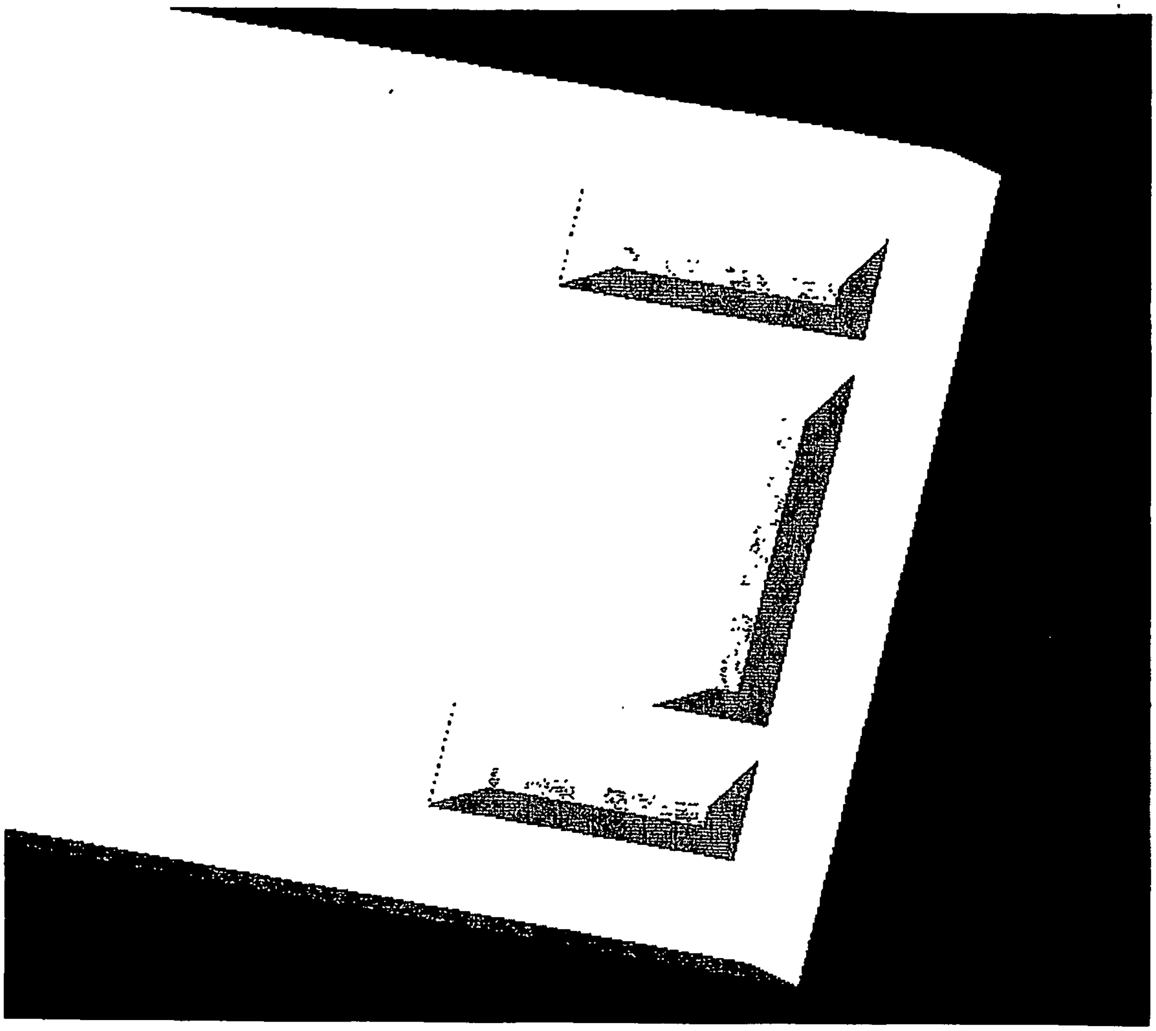
Because the signal has to pass from a dielectric loaded transmission line into a free space resonator, there is a significant impedance mismatch, which weakens the coupling. However, because of the resonant nature of the bandpass filter, weak coupling at the input and output ports is perfectly acceptable. The weak coupling is "tuned out" by the resonators, allowing a nearly perfect match at the input and output in the passband of the filter.

One possible procedure for making this coupling structure on the bottom wafer is now described. First, a masking layer for the anisotropic etch is deposited or grown on both sides of the wafer. This layer could be silicon dioxide or silicon nitride, for example. This masking layer is patterned and etched, leaving bare silicon where the via holes are to go. Next, a thin layer of seed layer metal is deposited on the front of the wafer. A photoresist layer is applied and patterned, and metal is electroplated through the mask. The photoresist is stripped off, and the seed layer metal is etched away using some standard process. The wafer, at this point, has the metal pattern on the front. The wafer is then etched in an anistropic silicon etch, such as Potassium Hydroxide in water. This forms rectangular pits in the back of the wafer. The size of the openings is made such that the pits go entirely through the wafer. The pits are positioned so there is a gold membrane across the top of the pit. The masking layer is etched away, and metal is deposited on the backside. This metal makes electrical contact with the front side metal through the etched pits. The back of the wafer now has a complete ground plane, with via holes going through to the front side.

The two figures below are drawings of the input/output coupling structures. The first is a drawing of the metal on a wire frame drawing of the silicon wafer. Not shown is the metal coating the bottom of the silicon wafer. The second drawing is a solid drawing of the same structure seen from the bottom of wafer one, illustrating the position of the via holes.



[redacted]



This embodiment of a cavity resonator band pass filter has several advantages over the current state of the art. Because of the high accuracy of micromachining, tuning of the filter is not required. Traditional waveguide filters with similar insertion loss characteristics are substantially larger and heavier, and are more difficult to connect to a microstrip line. They also requiring tuning, which is expensive. Other MEMS filters, based on suspended metal lines, can be as small or smaller than this embodiment, but have higher insertion loss due to the more concentrated currents. Suspended metal line MEMS filters are also susceptible to microphonics.

An alternate embodiment of this invention uses suspended silicon beams coated in metal as the resonant elements. The process for making these is very similar to the method described above for the cavity resonator filters. In the embodiment described

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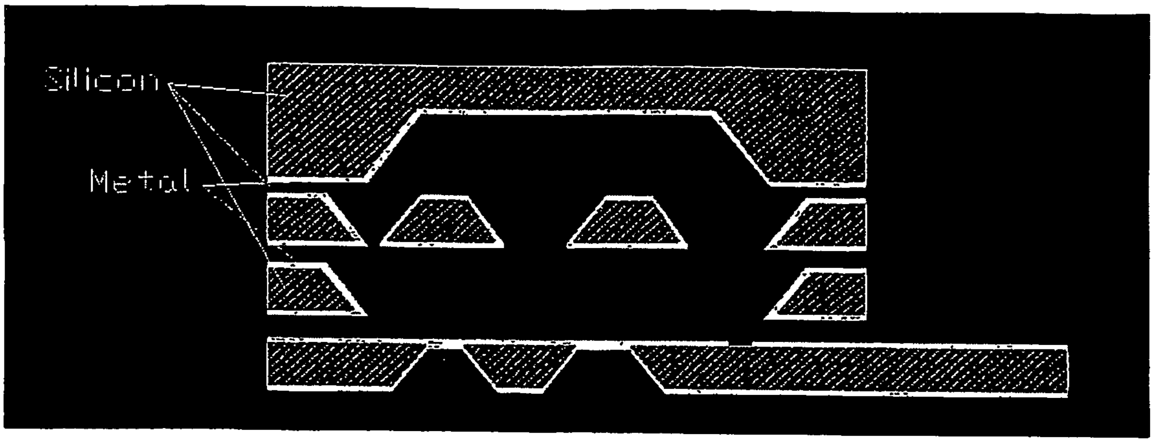
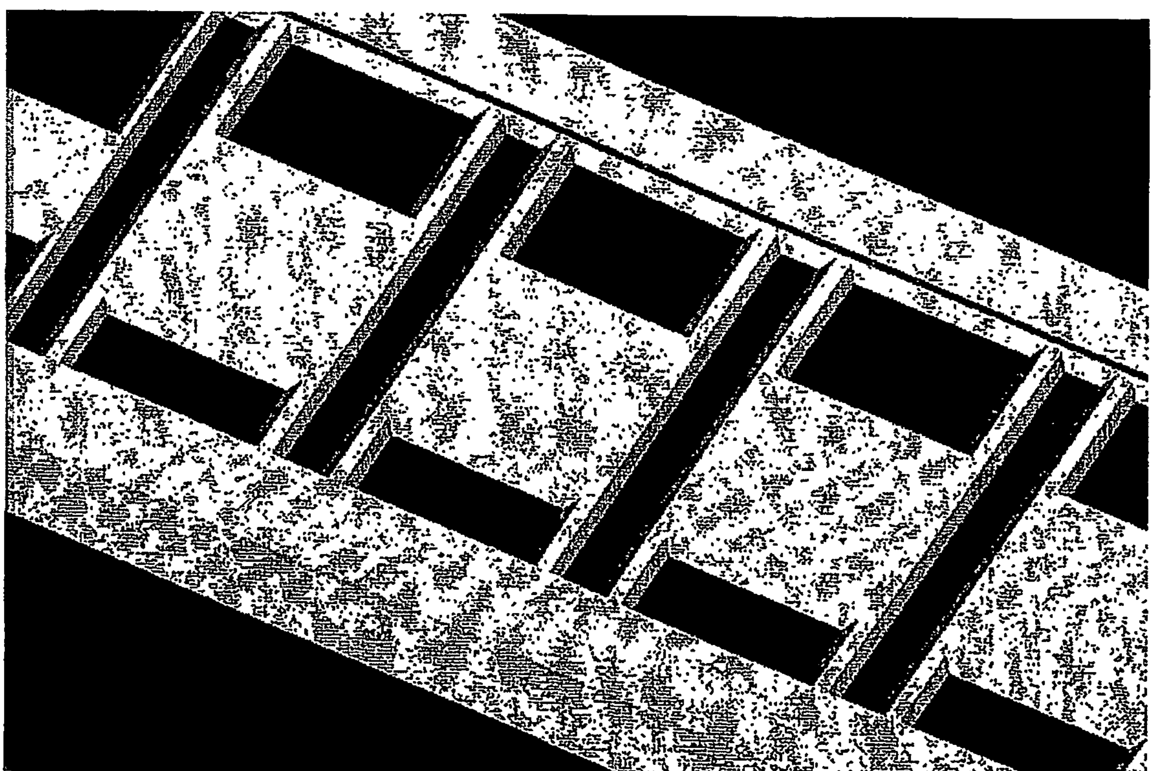
now, four separate wafers are used. The fabrication steps for the wafers are similar to those described above. A cross section of one such filter is shown in the figure below.



The three-dimensional drawing shown below shows the resonator structures. These are normally not visible, as they are completely encased in the cavity.



[redacted]

This method of using beams has the advantage of reducing the size of the resonators substantially, at the expense of a lower resonator Q, and hence increased insertion loss. The resonator Q should still be superior to the suspended resonator type filter described above.

In addition to the benefit of reduced device size, the beam structure relieves some of the requirements for dimensional accuracy. Whereas the resonant cavity type filter required all of the etched cavity dimensions to be very precise, with this type of filter only the wafer in which the beams are formed has very high requirements for accuracy. This accuracy is not difficult to achieve, as all of the features formed are self-terminating in an anisotropic silicon etch, removing the need for precise etch depth control.

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Application papers not suitable for publication

SN 60424620 Mail Date 11-07-02

☐ Non-English Specification

☑ Specification contains drawing(s) on page(s) ✓ or table(s) ____

☐ Landscape orientation of text ☐ Specification ☐ Claims ☐ Abstract

☐ Handwritten ☐ Specification ☐ Claims ☐ Abstract

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☐ Improper line spacing ☐ Specification ☐ Claims ☐ Abstract

☐ Claims not on separate page(s)

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☐ Drawing objection(s)

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